The Vermont Legislative Research Service

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Commercialization of Legacy Nutrients

In December 2014, the White House Office of Science and Technology Policy along with several other agencies started the Nutrient Sensor Challenge. The purpose of this challenge is for competitors to develop and deploy sensors for nutrients in America's waterways. The two nutrients of concern are nitrogen and phosphorus. The announcement states that these nutrients come from a variety of sources, "including legacy contributions from years past."[1] This means that these nutrients are not only currently entering waterways in but also that contributions from years past are producing the high levels seen today.

Lake Champlain has high concentrations of phosphorus. These high concentrations are negatively affecting the lake by damaging ecosystems and causing algae blooms. In recent years, Vermont has been actively trying to reduce phosphorus concentrations in the lake. This has historically been expensive and difficult to do, which is why there is currently an investigation into whether there is potential to commercialize these nutrients for profit. Phosphorus is a finite material and the easily accessible phosphorus reserves are being depleted. As the easily accessible supply of phosphorus in the world decreases, the price of phosphorus will likely increase in the market making these commercialization techniques more profitable.[2]

Phosphorus has the greatest potential for commercialization due to various uses and high concentrations in Lake Champlain. Through a commercialized phosphorus removal process, it may be possible to profit from the reduction of phosphorus concentrations of both water in the lake and water flowing into the lake. New technologies are being developed that have the potential to achieve this goal. Some of these technologies are: hydroponic farming, organic systems (biochar and algae filtration systems), nano-technology, and improved wastewater treatment facilities.

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[1] Tamara Dickinson, "Innovating to Protect our Waterways," White House Office of Science and Technology Policy, December 17, 2014, accessed April 3, 2015, https://www.whitehouse.gov/blog/2014/12/17/innovating-protect-our-waterways.

[2] Michigan State University, "New method to remove phosphorus from wastewater," ScienceDaily, August 15, 2012, accessed April, 10, 2015, http://www.sciencedaily.com/releases/2012/08/120815112243.htm.

Phosphorus enters Lake Champlain largely through "nonpoint sources," which are generated by runoff and erosion across the landscape, as opposed to "point sources" which can be wastewater treatment facilities and storm water discharges that are conveyed by a pipe.[3] Relative to nonpoint sources, point sources are easy to regulate, because the water is being stored or transferred within a constructed system.

Since 2007 phosphorus levels have been stable or slightly increasing, with nine of the thirteen segments of the lake (Figure 1) exceeding established targets for phosphorus concentration levels in 2010. Flooding in 2011 caused a large spike in phosphorus concentration levels--the largest spike since 1990 in certain parts of the lake. The greatest increases in phosphorus levels in the last five years were in the Main Lake, Burlington Bay, and Missisquoi Bay. Many other areas of the lake were also affected and exceeded their annual targets.

Current Actions by Vermont

Vermont issued its first TMDL (Total Maximal Daily Load) for phosphorus in Lake Champlain to the EPA in 2002. TMDL is a measurement of how much of a certain nutrient can flow into a body of water each day, while maintaining water quality standards for that body of water. A TMDL provides the state with a measurable goal of phosphorus loading, around which it can better plan its policy. This is just one of many policy solutions implemented to attempt to prevent increasing the amount of phosphorus in Lake Champlain. In 2011, this TMDL was rejected because the EPA was not convinced "that the necessary nonpoint source reductions will actually occur."[4] Currently, the EPA, along with Vermont officials, is working to revise the TMDL for Vermont's portion of the Lake; this is predicted to be done by mid-2015. Starting in 2002, however, Vermont began to implement a number of policies to attempt to stem phosphorus loading into Lake Champlain. These programs were: The Storm water Management Program, Green Infrastructure/ Low Impact Development Program, Vermont Better Back Roads Program, River Management Program, Lake Shoreland Program, Wetlands Program, and the Agricultural Resource Management Division. As of 2014, these programs had cost $4,375,888 total since 2005. Additionally, between 2006 and 2013, there were 50 programs awarded federal grants through Section 319 of the Clean Water Act.[5]

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[3] Vermont Agency of Natural Resources, Vermont Agency of Agriculture, Food, and Markets, Vermont Agency of Transportation, "Vermont Lake Champlain Phosphorus TMDL Phase 1 Implementation Plan," State of Vermont, May 29, 2014, accessed April 5, 2015, http://www.watershedmanagement.vt.gov/erp/champlain/docs/LCTMDLphase1plan.pdf.
[4] Vermont Agency of Natural Resources, "Vermont Lake Champlain Phosphorus TMDL Phase 1 Implementation Plan."
[5] Vermont Agency of Natural Resources, "Vermont Lake Champlain Phosphorus TMDL Phase 1 Implementation Plan."

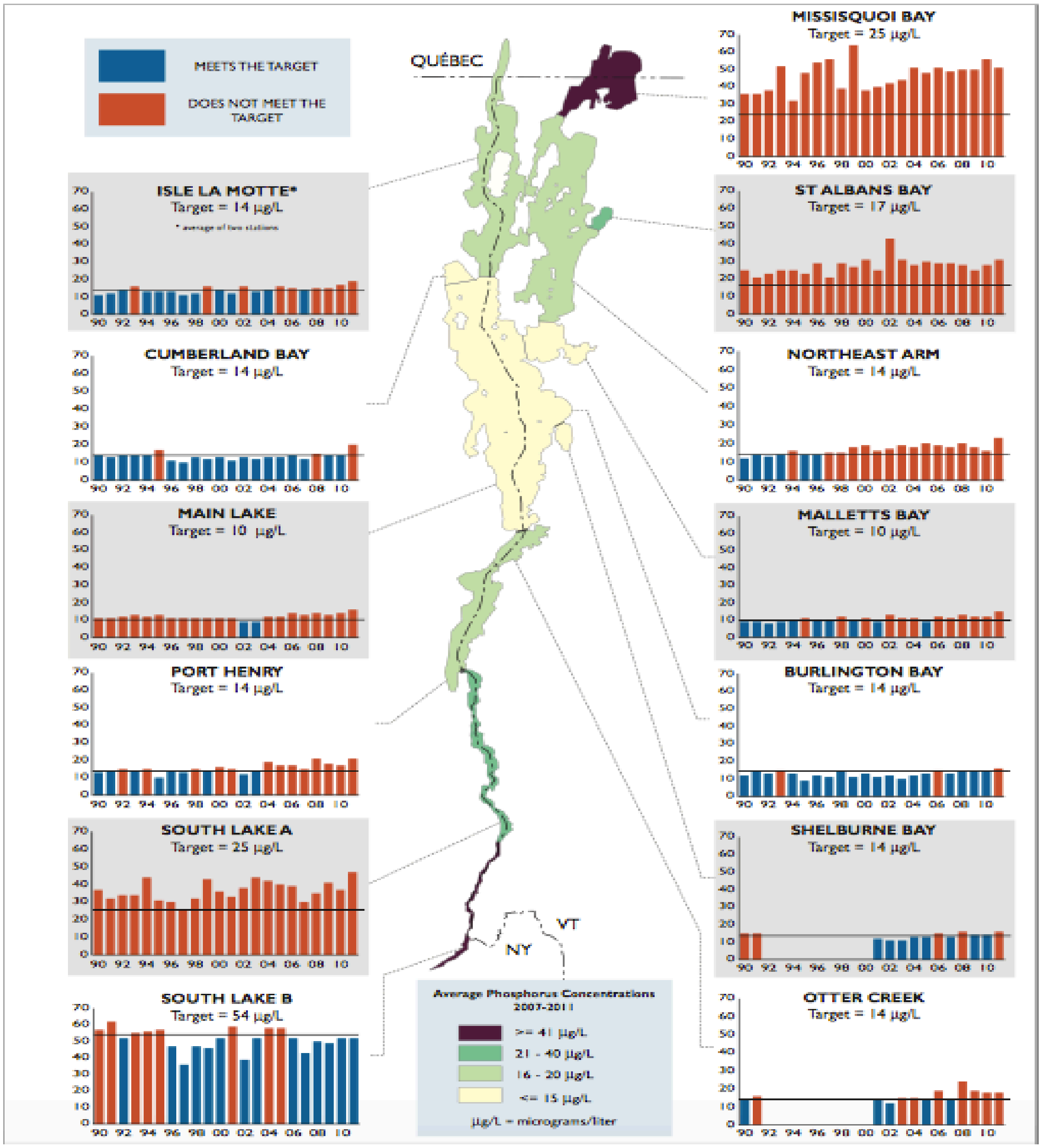

Figure 1: Phosphorus Target Levels and Actual Levels for the 13 Lake Segments

Source: Lake Champlain Basin Program (LCBP), "State of the Lake and Ecosystems Indicators Report," LCBP, 2012, accessed April 3, 2015, http://sol.lcbp.org/PDFs/Fig3-PChart.pdf

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Ways to Reduce Phosphorus In-lake

Reducing phosphorus loads in lakes can be an intrusive and damaging process. Many conventional removal methods can have detrimental side effects on the environment they are seeking to improve. This has led to new, potentially profitable, innovations that can reduce phosphorus in waterways in less environmentally degrading ways.

In an investigation, the state of Washington Department of Ecology found numerous ways to limit the amount of algae growth in state lakes. Several of the processes found to be effective include the removal of phosphorus from the water.

- **Nutrient Diversion**- The installation of drainage channels or pipes to divert nutrient-rich waters to the downstream side of lakes. This, however, could create large engineering costs, diversion of streams, which can interfere with fish runs, and impact the lake segments receiving nutrient rich water.
- **Dredging**- The removal of lake sediment to eliminate nutrient-rich sediments. Dredging has the potential to improve water quality, deepen the water body, and control aquatic rooted vegetation. Drawbacks include the temporary destruction of habitat, resuspension of sediments, and extremely high costs due to equipment, permitting issues, and soil disposal.
- **Nutrient Inactivation**- Aluminum, iron, or calcium salts can inactivate phosphorus in lake sediments. These nutrients settle and form a layer that acts as a barrier between the phosphorus in the sediment on the bottom and the water. The downside to this method is that none of the nutrients are actually removed from the lake they are "locked-in" to the sediment.[6]

Hydroponics: Farming on the Lake

Hydroponic farming is defined as "a technology for growing plants in nutrient solutions (water containing fertilizers) with or without the use of an artificial medium (sand, gravel, vermiculite, rockwool, perlite, peat moss, or sawdust) to provide mechanical support. Liquid hydroponic systems have no other supporting medium for the plant roots, [whereas] aggregate systems have a solid medium of support. Hydroponic systems are further categorized as open (i.e., once the nutrient solution is delivered to the plant roots, it is not reused) or closed (i.e., surplus solution is recovered, replenished, and recycled)."[7] Hydroponic farming could possibly be used to remove phosphorus from Lake Champlain. Currently, the EPA is working with the University of St. Thomas on ways to adapt hydroponic farming to remove phosphorus from Como Lake in Saint Paul, MN. The goal of this EPA research is to see if hydroponic farming can significantly reduce phosphorus while being profitable for the farming operation. The EPA's expected outcomes of this ongoing study are "improved lake water quality; production of nutritious, locally-grown vegetables; creation of educational opportunities for the public related to urban water quality."[8] There is no evidence that other states or countries are currently engaging in large-scale hydroponic farming as a means to reduce phosphorus or other nutrients from a waterway.

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[6] Washington State Department of Ecology, "Algae Control Program," accessed April 10, 2015, http://www.ecy.wa.gov/programs/wq/plants/algae/lakes/lakerestoration.html.

[7] Merle Hensen, "What is Hydroponics," University of Arizona, 2013, accessed April 5, 2015, http://ag.arizona.edu/ceac/what-hydroponics.

[8] Environmental Projection Agency, "Adaptation of Hydroponics to Remove Excess Phosphorus from Urban Lakes," August 15, 2014, accessed April 5, 2015, http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/10282.

New Hampshire Experiment

In the 1980s, the EPA deemed Kezar Lake in New Hampshire "the highest priority for restoration" in the state. The treatment decided upon by the EPA was a combination of wetlands management and aluminum salt injections on the lake bottom.[9] The aluminum salt (a 2:1 ratio of Al_2SO_4 : $NaAlO_2$) was shown to be effective at deactivating phosphorus in a test plot of the lake. This result led to a larger portion of the lake receiving treatment. The lake was then monitored for 4 years. After 4 years, the lake had returned to phosphorus levels close to those pre-treatment. The levels at the conclusion of that 4-year watch period, however, were more stable and safe for recreation.[10] The other aspect of this project was "wetlands manipulation." This part of the project involved raising the water levels in Chadwick Meadows, an area around Lion Brook, a tributary to Kezar Lake. The central idea behind this wetland manipulation was that "macrophytic nutrient uptake and sedimentation of suspended particulates" would be encouraged by the plant life.[11] This piece of the overall project did not greatly affect the phosphorus load in the lake. Nevertheless, it was fairly inexpensive, and helped to create wetland habitat and promote some sedimentation.

In-lake Algae Filtration

Clear as Water (formerly known as Algevolve) is a company that uses algae as a water treatment system to remove nutrients from the water, and commercialize the by-product. Rick Johnson, of *Clear as Water*, states that there are three current markets for the final product of algae.[12] The first market is for bio plastics, the second is for soil enhancement, and the third is for fuel/energy (Figure 2). The company only chooses to implement its system when the estimated cost-benefit is at least net zero or there is opportunity for profit. Currently, this system is being used in a freshwater lake in Massachusetts to remove algae from the water.

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[9] Tetra Tech, Inc, "Watershed Protection: Clean Lakes Case Study: Phosphorus Inactivation and Wetland Manipulation Improve Kezar Lake, NH," Environmental Protection Agency Office of Water, March 6, 2012, accessed April 15, 2015, http://water.epa.gov/type/lakes/kezar.cfm.

[10] Tetra Tech, Inc, "Watershed Protection: Clean Lakes Case Study."

[11] Tetra Tech, Inc, "Watershed Protection: Clean Lakes Case Study."

[12] Rick Johnson (employee of Clear As Water), communication with authors, April 15, 2015.

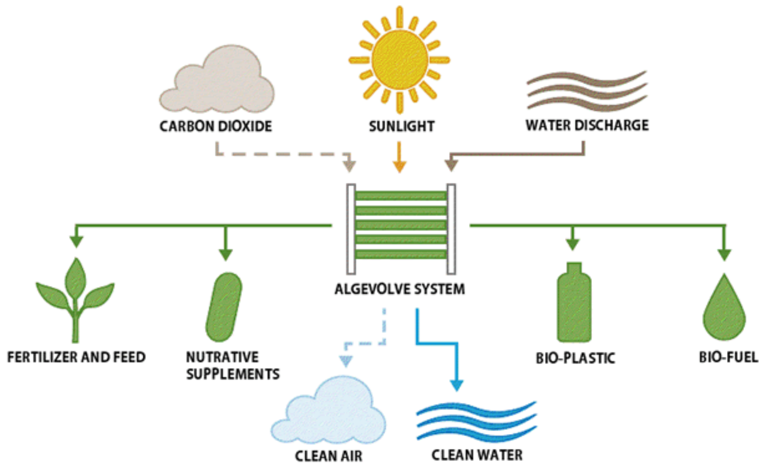

Figure 2: *Clear as Water* publication displaying input-output of their process

Source: Algevolve, "Renewable Products," accessed April 20, 2015, http://algevolv.com/pages/renewable-products.php.

Florida

Lake Okeechobee is a shallow fresh water lake in Florida that has become eutrophic due to high levels of phosphorus and nitrogen. In 1987, the state invested $500,000 on research into the harvesting of aquatic weeds to determine the commercial viability of phosphorus extraction. Over the course of the year the study removed over 1.5 tons of phosphorus from the lake. These results were then extrapolated to determine what the return on the investment would be if the program were expanded. They found that the weed removal would cost the state between 3.5 and 4 million dollars and would remove up to 40 tons of phosphorus. This equated to a cost of about $80,000 to $120,000 per ton. Recovering money by selling the products was only expected to yield between $73,000 and $292,000 in total.[13]

Removal of Phosphorus in Wastewater Treatment Plants

Phosphorus removal from point sources can potentially be commercialized to produce a profit from by-products and yield cleaner output. Current practices can be inefficient and produce harmful by-products. Research is being done to develop more cost effective phosphorus removal processes. While these techniques will not directly reduce the amount of phosphorus already in Lake Champlain, they would be able to limit and commercialize the amount of phosphorus entering the Champlain watershed.

[13] Sun Sentinel (put the city where this newspaper is published in parentheses), "Floating Weed-eater, Several Experimental Projects Seek to Lower Nutrient Levels in Lake Okeechobee," January 28, 1988, accessed April 15, 2015, http://articles.sun-sentinel.com/1988-01-24/news/8801050270_1_phosphorus-aquatic-weed-lake-okeechobee.

Wastewater Algae Filtration

A study in conducted in Sweden looked at using microalgae (small algae grown in a hydroponic environment) to create a water treatment system that would not only remove phosphorous and other nutrients from the water, but could potentially extract these nutrients for sale. The study concluded that algae filtration systems are effective in removing phosphorus from water in the right conditions. Results of this study came from only one water treatment system in Sweden, but the results were promising. The study reported that the biomass created by the water treatment system has value, but it is difficult to separate the parts that do have value from the parts that do not.

MetaMateria

A Michigan State University professor in collaboration with a company in Ohio, Metamateria Technologies, has been working on designing new phosphorus absorption technology. This technology utilizes a nano-media (a porous ceramic material) made with iron particles to chemically attract and draw out phosphorus from treated water. According to Professor Safferman, the nano-media extraction process is cost-effective in producing phosphorus relative to mining it. It also reportedly has the ability to remove large amounts of the nutrient from the wastewater.[14]

Biochar

A 2011 study developed by the University of Florida (UF) found that using an organic material called "biochar" is an effective and affordable solution to remove phosphate from water. Additionally, this process also yields methane gas that is usable as fuel as well as phosphate-laden carbon suitable for enriching soil. The researchers created biochar from culled beets, scraps, and weeds from shipments of sugar beets. In a test of biochar in wastewater treatment, it removed about three-fourths of the phosphates from the wastewater. The biochar can then be used as a slow release fertilizer. The process was found to be sustainable, but the question lies within commercialization of end products. Previous studies by UF have found that there are potential values to producing methane gas using this waste. A major challenge facing these researchers is "making biomass technology more cost-effective."[15]

Wastewater Treatment Byproduct Removal: Sludge

The Fraunhofer Institute in Germany has been researching ways to extract phosphorus from wastewater sludge. The German Institute uses an electrochemical process to

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[14] Michigan Sate University, New Method to Remove Phosphorus from Wastewater."

[15] University of Florida, "UF Researchers Develop Method to Remove Phosphate from Water, Using Biochar," May 1, 2011, accessed April 10, 2015, http://news.ufl.edu/archive/2011/05/uf-researchers-develop-method-to-remove-phosphate-from-water-using-biochar.html.

precipitate struvite, magnesium ammonium phosphate.[16] The process is conducted in wastewater treatment plants (point sources), where water molecules are split with and separated from phosphorous molecule. This process uses no chemicals and researchers say that it does not use much energy. The end result of the process is phosphorous crystals that can be used as fertilizers.[17] There is a stigma associated with using sludge, which is human waste.

Conclusion

There are a number of ways that phosphorus levels in Lake Champlain are already being reduced. The research shows that there is potential for commercialization, but the technology needs further development. The majority of the research pertains to decreasing levels of phosphorus entering the lakes via point sources. Discovering more cost-effective methods of removing phosphorus from wastewater facilities could increase profit margins for firms and also mitigate costs through sale of byproducts. Hydroponic farming has potential, however, its scalability remains in question. Algae filtration systems are another method of phosphorus extraction and markets for byproducts appear to be profitable. Research is still necessary to determine more effective methods of phosphorus removal. As a result, there are remaining questions of the cost of extraction, creation of end products, and profitability of these products in the marketplace. As global phosphorus reserves continue to be depleted and more phosphorus enters Lake Champlain, there could be increased incentives in the near future for the commercialization of legacy nutrients in Lake Champlain. A final question research has not yet touched on is the total net effect on the environment and how EPA regulation will influence the implementation of these technologies.

This report was completed on May 10, 2015 by Becka Brolinson, Matthew Donovan and Jonathan Gonin under the supervision of Professors Jack Gierzynski, Robert Bartlett and Eileen Burgin in response to a request from Representative Sheldon.

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[16] Linda Paulson, "German Researchers Create Fertilizer From Sludge, Wastewater," RWL Water, August 17, 2012, accessed April 5, 2015, http://www.rwlwater.com/german-researchers-create-fertilizer-from-wastewater/.
[17] Linda Paulson, "German Researchers Create Fertilizer From Sludge, Wastewater." http://www.rwlwater.com/german-researchers-create-fertilizer-from-wastewater/.